# Using SLAMM to better understand Sea Level Rise on the Francis Marion National Forest

## GIS Capstone Project

http://arcg.is/2a6V1qO

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## Abstract

How is sea level rise influencing the ecosystems and related management? This paper will discuss the examining of the Francis Marion National Forest via SLAMM & Satellite Imagery to better understand the sea level rise influence on ecosystems and to better related Coastal Management Decisions. Running the Sea Level Affecting Marshes Model will allow for users to understand where there will be potential changes in the seascape and how to prepare for these locations and formulate restoration processes for the future. Can increased sea level and salinity intrusion amplify coastal drought possibilities and could it be an indicator for increased fires? This model will help answer these types of questions. Exhausting this model coupled with satellite imagery for comparison purposes will allow for further awareness of the effects of increased tidal flooding and how the forest can plan for these potential problems.

## Introduction/Background

Within the past few decades, GIS has become much more prevalent in Coastal Management. Using geospatial technology to investigate terrestrial landscapes has been around for much longer and only as of late, has it been recognized as a vital part of understanding our coastal communities. The technology matured with its focus on the land; however, coastal habitats are entirely different and those methods and procedures cannot simply be applied to a completely different environment. Therefore, more aquatic based models and tools have been created specifically with understanding our coasts.

The Sea Level Affecting Marshes Model (SLAMM) is a simulation of wetlands and shore line changes during a long term sea level rise. The model uses digital elevation data and can incorporate various parameters ranging from impervious surfaces, salinities, dike locations, and more to determine where sea level rise will be an impact. Combining the results of this model with change detection analysis from Landsat 8 images will allow for understanding of the past, which will help in confirming the predictions are practical.

The following paper will examine related literature, SLAMM's results and expectations for the Francis Marion National Forest, change detection analysis results, and the anticipated changes from both methods. The effectiveness of the model for future uses in predicting changes in order to provide support for the Forest Plan will also be investigated. Coastal Management needs to be improved and if a model can help provide evidence for better policies, then it should be utilized fully.

**Literature Review**

The following articles are areas of research that support my project. They range from the basics of using GIS for Coastal Managements, to background on the Francis Marion Forest, as well as specific studies using similar models in different coastal regions. Each source of information relates back to why studying wetland growth in coastal regions is essential and how to better convey that significance to coastal resource managers.

- <u>Geographic Information Systems applied to Integrated Coastal Zone Management</u>:
    - This paper focuses on the overall benefits of using GIS for coastal zone management. Coastal zones provide vital social, economic, and environmental resources; in order to better manage these areas, changes need to be prepared for with mitigation policies in place. However, evidence for policies comes from scientific studies. Using GIS to provide that evidence is undeniably the best course of direction. Within the coastal environments, the littoral areas,and  the interactions of marine and terrestrial processes, need to be understood better. Since GIS specifics the spatial and temporal dynamic processes and their evolutions, it is the best tool. This paper provides three applications of GIS: "1) In

coastal hazards management GIS helps with statistics analysis, needed to carry out a multivariate spatial-temporal model that estimates the probability of a hazard occurrence; 2) Dealing with shorelines corresponding to different years, GIS allows the analysis of evolutionary trends to define the behavior of the system; 3) GIS used in studies of the evolution of dune fields is essential in order to estimate dune migration rates and analyze all the variables involved in this process" (CoastGIS 101).

- The first application discusses the many factors involved in studying coastal hazards in the Mediterranean Sea. To determine the safety of the coastal waterfronts, elevation, swell information, streams, rock fall occurrences from cliffs, erosion and human impacts are all necessary data sets. With GIS, modeling the data to map the unstable areas and to determine the at risk elements is much easier. Vulnerability zones can be mapped by overlapping the hazard maps and the at risk maps. From those analyses, decision support systems can be implemented.
- GIS can also understand shoreline evolution by comparing previous cartographic data. Determine coastal changes with current imagery allows for the understanding of flooding and sea level rises. Additionally sand dune transitions can also be determined. Specifically, data sets related to wind transport, swell, sediments can all be incorporated into the geodatabase as well as field survey data.
- This paper concludes that GIS implementation is still a new and growing field, but can be vital in supporting policies by providing spatial, visual, and statistical analysis. Land management has utilized GIS more so than coastal environments and that needs to change.

- Francis Marion National Forest –Draft Final Environmental Impact Statement
    - Every ten years, the National Forest revise their Land and Resource Management Plan for each individual forest
    - For the expected 2016 Francis Marion Forest Plan, there is more emphasis on understanding climate changes effects on various aspects of the forest, specifically coastal ecosystems. There already has been rises in sea levels and

intense storms such as Hurricane Hugo, which nearly decimated the entire forest. It is vital to understand that "as saltwater flooding expands, low-lying coastal wet forest could become marshland where land-use barriers do not exist (Ervin et al., 2006). Tidal forests, including bald cypress swamps, may serve as sentinels for sea-level rise do to their low tolerance to salinity changes" (78). These tidal forests provide habitats for many wildlife species including endangered storks nesting in cypress swamps.

  - Saltwater intrusion: Sea level rise will increase the potential for saltwater intrusion into coastal freshwater tables and ground waters. Collaboration with local municipalities is needed to monitor saltwater intrusion.
  - Using SLAMM and imagery can provide evidence for better policies to include in the next Forest Plan. Using models and images can detect changes and can incorporate where restoration procedures will need to take place.

- <u>Drought and Coastal Ecosystems: An Assessment of Decision Maker Needs for Information</u> Fifth Interagency Conference on Research in the Watersheds**:** Kirsten Lackstrom, Amanda Brennan, Kirstin Dow - Carolinas Integrated Sciences & Assessments, University of South Carolina
  - This research program emphasizes the necessity of understanding coastal droughts and its differences as an ecological drought. The Coastal Carolinas experience these droughts due to freshwater deficiency and salt water intrusion from tidal flooding, both causing stress on the habitats and species. Their goals are to understand how and what to monitor and to develop mitigation strategies.
  - The research included interviewing recreational and commercial fisheries, recreation businesses, and land/refuge managers. These interviews defined the drought as changes in the availability and timing of freshwater, changes in water quality with increasing salinity and fluctuations.
  - The goal is to understand the impacts of the coastal drought. Beyond the direct physical impacts, what species and ecosystems are effected, what other stressors can be an issues (climate, human, biological), then how will the individuals and organizations be effected and what will the adaption responses be? Additionally, a

drought early warning system would be extremely helpful. To understand the salinity effects, the seasonal changes, the normal/baseline would be beneficial to all parties involved. Coastal droughts do exist and to be able to predict the increase flow of salt water can be done by SLAMM, then providing locations and potentials of coastal drought.

- <u>Sea-level rise and drought interactions accelerate forest decline on the Gulf Coast of Florida, USA</u>**:** Larisa R. G Desantis, Smriti Bhotika, Kimberlyn Williams, and Francis E. Putz
    - This study in Florida acknowledges that increased tidal flooding contributes to the "well documented decline of species-rich coastal forest areas along the Gulf of Mexico" (2349). While this study did not focus on using spatial and GIS technology for analysis, it did concentration on the specific species affected by tidal flooding and the increase of salinity's effects on their habitats. The recent rates of sea level rise along the Gulf Coast can be as high as 11.9mm/yr. These saltwater "intrusions cause reduced canopy tree regeneration, declines in over story tree species diversity.
    - Florida has low elevations and flat topography, making it vulnerable to shoreline changes and retreats. The specific area of study in Waccasassa Bay Preserve State Park included multiple study plots of 20m x 20m. Within these plots, live tree species such as cabbage palm, southern red cedar, live oak, and sugarberry and others were tagged and mapped in the early nineties and early two thousands. This survey style of research differs from my own, but provides recognition of past changes based on field data. The trees examined in this study similarly grow in the Francis Marion Forest in South Carolina. Acknowledging a study that determined changes in tree growth from salt water intrusion in the past will provide coastal resource management with evidence to conduct similar studies as my own to predict the future problem and drought areas. Heights and diameters of the trees were measured as well as the forest health, which includes stable isotype analysis "to investigate uptake if fresh ground water" (2350).
    - The method of the analysis included comparing tree survivorship from the early 1990s to the expected surviving trees in 2005. Their sea-level rise data was

calculated based on the Cedar Key Station from 1939-2005. La Nina events were included as well as weather data acquired from the Tampa Airport, leading to an average rate of 2.4mm/yr. The isotope analysis was collected using tree trunk cores. The sample was examined in a mass spectrometer to determine those oxygen and hydrogen values. Leaf samples were also examined to determine water stress.

  - The results of their study determined that coastal forests declined in species richness, the lower the elevations and the increasing flooding frequency. After 2005, the disappearance of the S. palmetto was in the most regularly flooding plot. The tree remained in plots with less than 26 weeks of tidal flooding. Additionally, regeneration of species declined in these frequently flooded plot as well as density. Using the weather data regarding La Nina, the effects of sea level rise were more intense during those drought times.
  - The study determined that tree species were affected negatively by tidal flooding events and salt water intrusions. Some species are more tolerant of the higher salinity, but their regeneration rates are not consistent. Using these lab and field studies, exposure to salt will effect tree species and their regeneration. Knowing this information helps provide significant reasons to perform predictive analysis tests in a format similar to my research. Using a model to predict flooding based on the past sea level rise will indicate the areas of salt water intrusion as well as potential coastal drought and fires.

- Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0.2) in the Lower Delmarva Peninsula - Northampton and Accomack counties, VA, -Somerset and Worcester counties, MD: By Delissa Padilla Nieves, Conservation Biology Program, National Wildlife Refuge System, Arlington, VA
  - This study focuses on the Delmarva Peninsula, along the eastern shore of Virginia and Maryland. This region includes barriers islands as well as the mainland, with coastal reserves and national wildlife refuges. Land types include beach, dunes, freshwater swells, maritime forest, marshes, and tidal flats all providing habitats for migratory birds and other species.

- This study area is similar to the Francis Marion National Forest study area since both include areas of wildlife refuges as well as a range in habitats from barrier islands to swamps, marshes and forests. Both regions experience frequent interactions with storms, storm surge, waves and wind. The differences are the extreme overwash that Assateague experiences, causing sediment transportation.
- This study uses expected sea level rise trends from NOAA's tides and currents website, the same source for my own study. Their goals are to project the effects of sea level rise on the coastal habitats, specifically within the wildlife refuges.
- "Within SLAMM, there are five primary processes that affect wetland fate under different scenarios of sea-level rise:
    - **Inundation:** The rise of water levels and the salt boundary is tracked by reducing elevations of each cell as sea levels rise, thus keeping mean tide level constant at zero.
    - **Erosion:** Erosion is triggered based on a threshold of maximum fetch and the proximity of the wetland to estuarine water or Open Ocean.
    - **Overwash:** Beach migration and transport of sediments are calculated based on storm frequency.
    - **Saturation:** Coastal swamps and fresh marshes can migrate onto adjacent uplands as a response to a rise in the water table
    - **Accretion:** Sea-level rise is offset by sedimentation and vertical accretion using average or site-specific values for each wetland category.
    - SLAMM integrates localized conditions of sea-level rise, wetland elevation changes (accretion and submergence), and wave-action erosion to simulate wetland conversions. Therefore, relative sea-level rise is estimated based on site-specific conditions" (6).
    - Similar to my study, GIS was used to process the data for the model. Elevation data is from the USGS NED, SLAMM codes were assigned to the National Wetlands Inventory Data, from the US Fish & Wildlife Inventory. The impervious surfaces data was from the National Land Cover Database 2001. All data was used at a 30m by 30, cell size. The climate scenarios they used included the A1B, 1 meter rise and 1.5 meter rise in 25 year increments starting at the NWI photo date until 2100.

- As mentioned previously, one of the differences between this SLAMM study and my own was Assateague's overwash issues. They accounted for this within the model by adjusting the default values to maximum width of the barrier island as well as including previous overwash events and by how much.
- The conclusion of their study reiterated the growth of wetlands and change of the shorelines. Wetlands were projected to convert to open water in some areas and migration of wetlands is anticipated on the other shores. The irregularly flooded marshes are expected to be the most impacted with a potential loss of 68%-91% for brackish and 37%-49% decline in salt marsh. Fresh tidal marshes are expected losses of 73%. The estuarine beaches expected gains in all their tested scenarios. Their major obstacles with the model is the lack of simple formulas for the overwash events in the barrier islands.

**Data**

This study has three required data sets. The digital evaluation data is 10 foot Spatial Resolution for Francis Marion Ranger District 2009 LiDAR. The slope is required and that is derived from the DEM. The National Wetlands Inventory provides the wetlands polygon shapefiles from the Fish & Wildlife Service. These are organized by types of wetlands and the surrounding land types. The average sea level rise data was collected from NOAA's Tides and Currents websites. The sea level trends are collected at various stations along the coast. For this study, I used the average of the Myrtle Beach and Charleston stations. Unfortunately there was not expansive historical data specifically for the Francis Marion National Forest, so the average of these two stations, both within 50 miles will suffice. For more extensive studies, there are various other parameters that can be applied such as the impervious surfaces, from the National Land Cover Datasets, Tidal Datum, historical erosion and accretion rates as well as beach sedimentation rates.

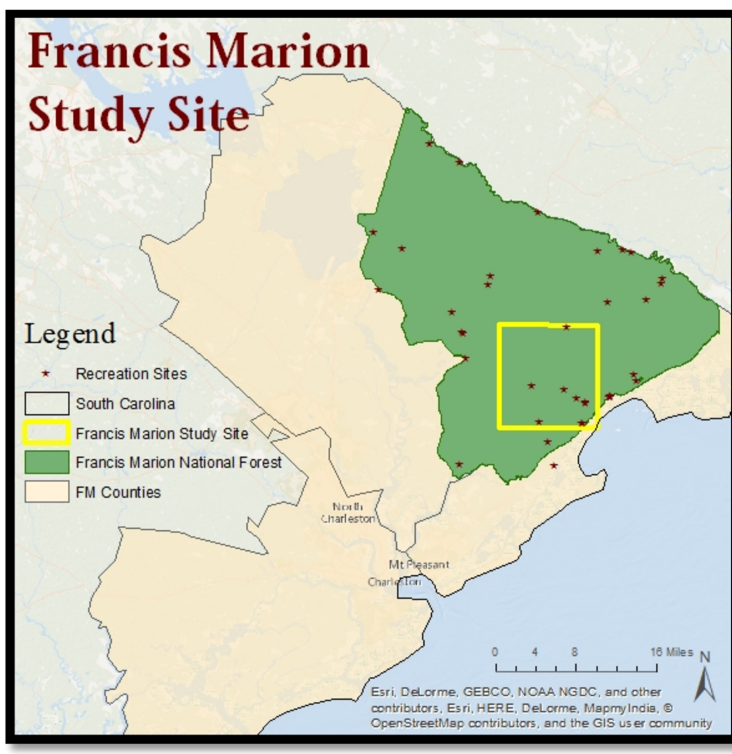
For my comparison purposes, I analyzed Landsat images expanding over Berkley and Charleston counties. The images are derived from the USDA National Agriculture Imagery Program (NAIP) taken during the growing seasons “leaf-on” throughout the U.S. The images are acquired at 1 meter ground distance with a spectral resolution at natural color (red, green and blue). Additionally, each image should have less than 10% of cloud cover.

For reference purposes, I acquired the SLAMM 3.0 Version outputs of a similar study area. This previous study used 0.4 meter rise on the Cape Romain Wildlife Refuge. This area is slightly southeast of my study site and it includes more marsh lands and barrier islands. However, this data provides good background on how the model functioned at the 3.0 version and a reference point for my results.

**Methods**

Study Area:

The Francis Marion National Forest is located north of Charleston, South Carolina. It was named after Francis Marion, known as a revolutionary war hero the “Swamp Fox.” The area is within the middle Atlantic coastal forest ecoregion with sub-tropical coniferous forest. Within Berkeley and Charleston counties, the forest includes over 250,000 acres.




Because of its location on the coast, it can be susceptible to hurricanes and flooding events. The landscape of the forest contains pine trees, swamps, marshes and cypress trees as well as various wildlife, such as the endangered red-cockaded woodpecker. Blocking direct access to the Atlantic Ocean is Cape Romain, the National Wildlife Refuge that includes marshes, creeks, and barrier islands, mostly accessible by boat only.

Model:

Sea Level Affecting Marshes Model (SLAMM) is a program initially funded by the EPA to provide details about coastal habitats in response to Sea Level Rise. The model can provide various outputs of sea level rise and the potential conflicts within coastal environments. The six main processes of the model are inundation, erosion, accretion, saturation, overwash and salinity. The required inputs include the digital elevation models and its resulting slope, as well as the national wetlands inventory converted to SLAMM codes. Additionally, the user has the choice of various sea level rise scenarios, ranging from 0.4 to 1.5 meters by 2100, or using the IPCC scenarios of A1, A2, B1, or B2. “Within SLAMM, there are five primary processes that affect wetland fate under different scenarios of sea-level rise:

> **Inundation:** The rise of water levels and the salt boundary is tracked by reducing elevations of each cell as sea levels rise, thus keeping mean tide level constant at zero.
> **Erosion:** Erosion is triggered based on a threshold of maximum fetch and the proximity of the wetland to estuarine water or Open Ocean.
> **Overwash:** Beach migration and transport of sediments are calculated based on storm frequency.
> **Saturation:** Coastal swamps and fresh marshes can migrate onto adjacent uplands as a response to a rise in the water table
> **Accretion:** Sea-level rise is offset by sedimentation and vertical accretion using average or site-specific values for each wetland category.

SLAMM integrates localized conditions of sea-level rise, wetland elevation changes (accretion and submergence), and wave-action erosion to simulate wetland conversions. Therefore, relative sea-level rise is estimated based on site-specific conditions” (Polaczyk, 2013).

Pre-Processing:

In order to run the model, there are three required datasets, DEM, Slope, and NWI. The 10ft DEM was obtained from the Forest Service from 2009 LiDAR data. It was then used to create the slope raster by the spatial statistic tool. The cell size of every raster was 10 by 10, based on the initial elevation model. All files are projected NAD 1983 State Plane South Carolina FIPS 3900 Feet Intl. These files were initially the original boundaries of the Francis Marion Forest, but for the sake of time, everything was clipped to the North portion of Charleston County, SC. This study site included a portion of the open water, river, and marshes as well as an extensive forest section. Both the DEM and slope were then converted to ASCII using ESRI's tool, raster to ASCII. The National Wetlands Inventory was downloaded from their website owned by the Fish & Wildlife Agency. In order for the model to recognize the wetlands code categories, they need to be converted to SLAMM codes. The table and description of codes is within the Appendix. The polygon file of South Carolina was clipped to the Berkley and Charleston Counties. This file was then converted to a raster based on the SLAMM code values. The raster to ASCII tool was also used for the wetlands raster. For the initial test run, the data was also clipped to a smaller Northern portion of Charleston County.

Sea Level trends have been on the rise in the recorded years. For this study, I ran the model for two different scenarios. The first is an average of the Sea Level Rise Trends values collected from two stations north & south of the forest. The Francis Marion sits between two stations on the east coast, the Myrtle Beach station and the Charleston Station. In Myrtle Beach, "The mean sea level trend is 3.9 mm/year with a 95% confidence interval of +/- 0.58 mm/year based on monthly mean sea level data from 1957 to 2015 which is equivalent to a change of 1.28 feet in 100 years" (NOAA Tides & Currents). While in Charleston, "The mean sea level trend is

3.21 mm/year with a 95% confidence interval of +/- 0.22 mm/year based on monthly mean sea level data from 1921 to 2015 which is equivalent to a change of 1.05 feet in 100 years" (NOAA Tides & Currents). For my purposes, I am taking the average of the two stations, which is 3.55mm/year. Based on these values, by 2025, there will be a 35.5mm increase. By 2050, there will be a 124.25mm increase, roughly 1/8$^{th}$ of a meter. These values certainly are not the worst case scenarios available, but rather estimates based on the past 60-80 years. Since the future is always uncertain, this study will focus just on the historical recorded values for the nearby areas.

The second scenario is the A1B Climate Change Scenario from the International Panel of Climate Change. This environment "describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies)" (IPCC, 2016).

Execution

Running the model included a few steps. To avoid any errors and a successful run, each input needs to be the same cell extent. Once all input are uploaded to the interface, the program counts all the cells. Next are the SLAMM execution options. This screen (see appendix D) allows for the user to select their sea level rise scenarios, their protection scenarios, and their specified outputs, such as GIS, rasters, gifs, or tabular data. This is the step where I selected the 0.4 Meter Rise Scenario as well as the IPCC A1B Scenario. Once all parameters are selected, the simulation can be saved and then begins a rather lengthy process of producing sea level rise impacts.

Change Detection Methods

The purpose of completing an unsupervised classification is to determine change between two Landsat8 images. These changes are to confirm whether or not SLAMM can predict similar changes with results that do not appear outside the realm of reason.

The images collected are already georeferenced, so the next step is to clip them according to the study site. From there, each image undergoes the unsupervised classification process based on 25 classes (just like SLAMM). This classification uses isodata clusters to better classify into 25 categories. From there each image is examined to highlight and identify the classifications, and then recoded into 10 categories based on similarities. The matrix union of the two images produces the changes of the amount of cells from 2005 to 2015. These values then are calculated to show the percent difference between the two years. These differences are compared to the SLAMM results to determine any similarities or differences.

Note: There will be differences due to the differences in categories that SLAMM provides, with its main focus on various wetlands type. As a novice in remote sensing, I am learning the best ways to determine the differences in land cover types, including the various wetlands and marshes.

## Results

The model produces various outputs. For my project, I selected the results to be displayed as rasters, gifs, and tabular data. The images show some change within the SLAMM color codes;

however, it is the number of cells for each category and their changes from previous years that supplies us with sea level rise evidence.

The most important outcomes of these results, in my opinion, are focused on the following categories: Estuarine Open Ocean, Tidal Flats, and Inland Fresh Marsh. These categories determine some of the most important consequences of increased sea level rise.

- The increase of **Estuarine Open Ocean** by **142%** in the 0.4 Meter Scenario, **161.19 %** in the A1B Scenario, **208.3%** in the 3.0 SLAMM 0.4 Meter Version and even **81.39%** in the imagery analysis proves that there will be more ocean water and it will be impeding on the previous areas of marsh land.
- The Tidal Flats show an increase in all three scenarios and in the image analysis, leading to the conclusion of more salt water coming in from the tides creating larger tidal flats. **Tidal Flats: 204.13%** in the 0.4 Meter Scenario, **199.45 %** in the A1B Scenario, **76.99%** in the 3.0 SLAMM 0.4 Meter Version and even **18.29%** in the imagery.
- The Inland Fresh Marsh show a decrease or no change at all in the three scenarios and a decrease in the image analysis, predicting less fresh marshes within the study site. This potentially could cause coastal droughts, however, it could also imply more fresh marshes moved inland, outside of the study site. **Inland Fresh Marsh: -0.28%** in the 0.4 Meter Scenario, **-1.24%** in the A1B Scenario, and **0.00%** in the 3.0 SLAMM 0.4 Meter Version.

As a novice imagery analyst, my classification of land cover categories did not match up to the exact SLAMM codes. However, the most important values are noted: an increase in water by 81.39% and a decrease in wetlands of 39.32%. These values prove that SLR will be affecting the Francis Marion Forest and that preventative measures need to be included within the Forest Plan.

**Obstacles, Benefits, & Limitations**

Running an unfamiliar model takes time to understand the processes and procedures. Overall, SLAMM is an extremely useful tool that provides value outputs. The major obstacles would be gathering data and matching their cell extent to one another exactly. Without GIS experience, running this model would prove very difficult, in particular, converting the data to the appropriate formats and matching their cell size would be daunting.

<u>Benefits</u>

- SLAMM provides extensive looks at the changes in all wetlands types
- Predicts the changes within your specific parameter request
- Allows for various climate scenarios to be explored
- Understanding potential increases in sea level rise will allow for better preparation for recreation sites as well as transportation
- Once the areas of interest are located, ecologists or biologists can determine the species in those areas that may need protection
- SLAMM provides tabular results, GIS outputs, gif formats, rasters for every parameter provided

<u>Limitations</u>

SLAMM

- Higher Resolution = slower run time
- ASCII Binary files require extensive storage
- A lot of inputs can be difficult to access and hard to convert for the average GIS user

Imagery analysis

- Imagery requires an expert eye
- High Resolution leads to difficult classification
    - Example: Clouds = Driveways
- Various colors of wetlands make for difficult classification: low tide or high tide, sand influx, recent storm effects, etc.

## Conclusions

The Sea Level Affecting Marshes Model is a valuable tool for coastal management. This program will comprehend what type of marshes or wetlands will be affected and by how much. The percent change between each year provides the user with a better understanding for each time step. Coupled with the image processing and the SLAMM 3.0 version outputs, it is clear that even those the values are not identical, the results are within a reasonable range from one another. The model produced appropriate results to which the Forest Plan can use to create restoration and preventive policies. The next step in this project would be to incorporate biological or ecological data sets. These datasets were difficult to acquire during this timeframe, however coupling the species data and the areas of potential flooding and habitat changes, the prediction of future species effects are possible. Not only species impacts, but a decrease in fresh water and an increase in salt marshes will rate high on the coastal drought possibility, finding that data and incorporating it will allow for understanding of potential fire locations. Coastal drought can dry out flammable marshland soils, leading to possible long burning peat fires. Increases in tidal flooding can cause salinity stress on species rich coastal forests. A nearby county, Georgetown, has saltwater intrusion issues, which SLR can exacerbate; using the results from the model will allow for when and where the SLR can affect the drinking water within the National Forest and how to prepare for it. From there the Forest Plan can determine the best plans of action to arrange for the future, every only ten years at a time if interested.

The Francis Marion Forest Plan specifically wanted to understand how sea level rise is influencing the ecosystems and how to create related management. These results show where the sea level rise will affect and how the environments will change. The next step is to collaborate with species knowledgeable people in those impacted areas. They will have much better opinions than my own to understand how to start preparing for these changing habitats.

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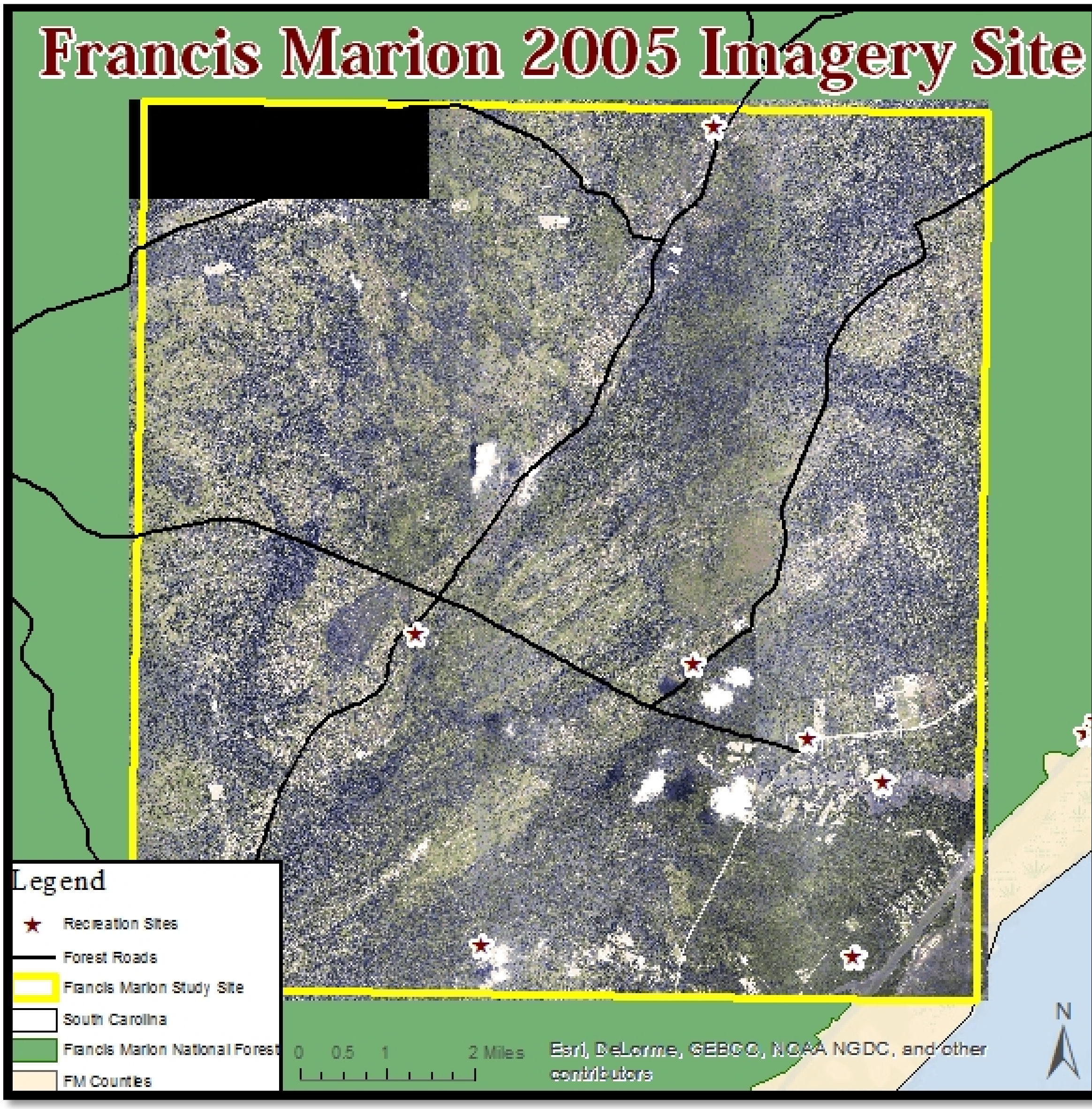
**Appendix A**

Francis Marion National Forest Map

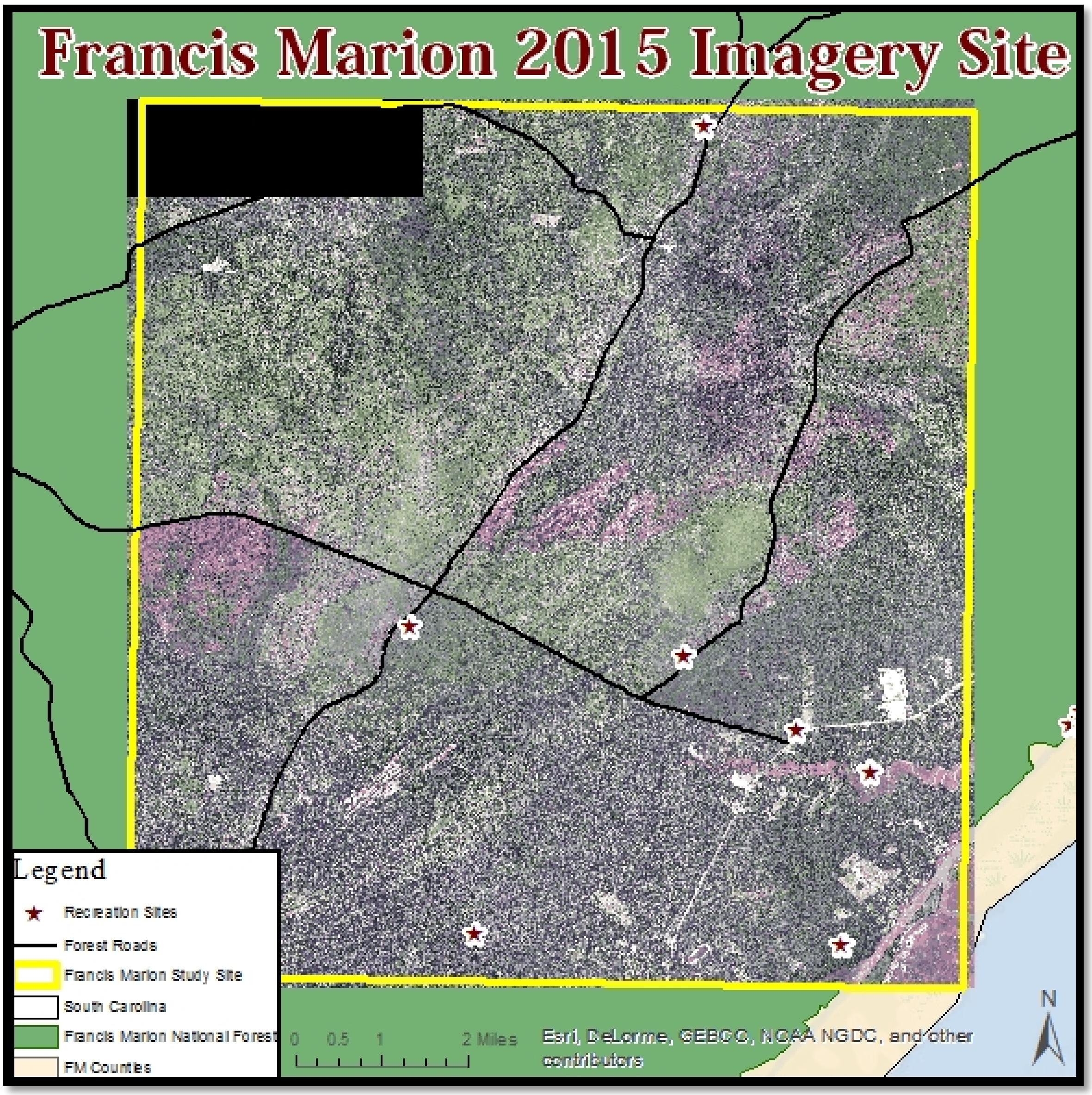
## Appendix B

Francis Marion National Forest 2005 Imagery
Unsupervised Classification



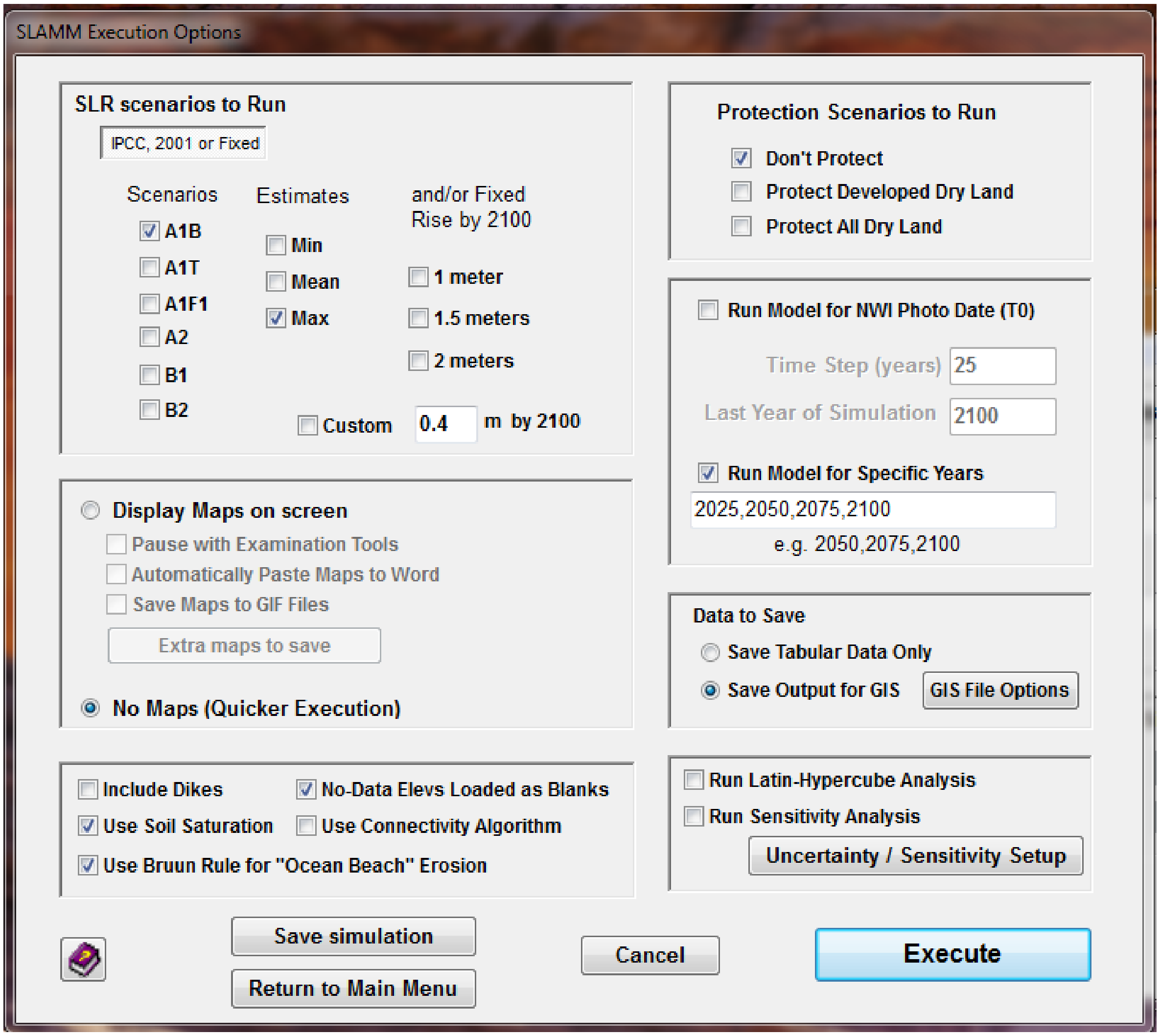
**Appendix C**

Francis Marion National Forest 2015 Imagery
Unsupervised Classification

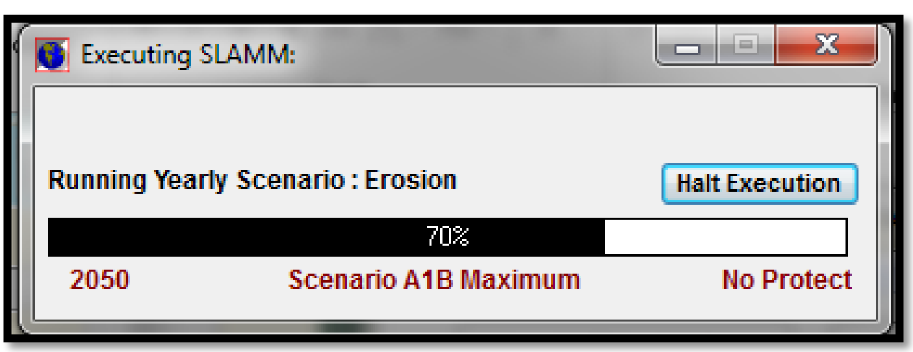


## Appendix D

SLAMM Interface 1.

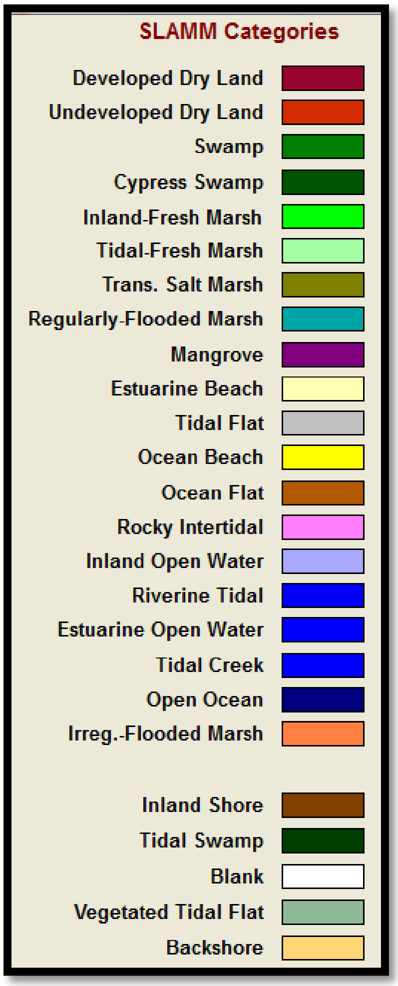



SLAMM Interface 2.



## Appendix E

SLAMM Legend:



**Appendix F**

## *NWI to SLAMM Category Conversion*

The tables provided below may not provide a perfect linkage between the Cowardin classification system (as utilized by NWI) and SLAMM land-cover classes. However, they provide a good starting point. Professional judgment and site-specific factors should always be taken into consideration when examining resulting SLAMM land-cover maps. Elevation analysis can also be instructive.
Please note that an Excel database containing conversions between NWI classes and SLAMM land-cover classes is included as part of the SLAMM installation package (it is located in the same directory as the SLAMM executable is installed).

**Table 4: NWI Classes to SLAMM 6 Categories**

| | | NWI code characters | | | | | |
|---|---|---|---|---|---|---|---|
| SLAMM Code | Name | System | Subsystem | Class | Subclass | Water Regime | Notes |
| 1 | Developed Dry Land (upland) | U | | | | | SLAMM assumes developed land will be defended against sea-level rise. Categories 1 & 2 need to be distinguished manually. |
| 2 | Undeveloped Dry land (upland) | U | | | | | |
| 3 | Nontidal Swamp | P | NA | FO, SS | 1, 3 to 7, None | A,B,C,E,F,G,H,J,K None or U | Palustrine Forested and Scrub-Shrub (living or dead) |
| 4 | Cypress Swamp | P | NA | FO, SS | 2 | A,B,C,E,F,G,H,J,K None or U | Needle-leaved Deciduous forest and Scrub-Shrub (living or dead) |
| 5 | Inland Fresh Marsh | P | NA | EM, **f **** | All None | A,B,C,E,F,G,H,J,K None or U | Palustrine Emergents; Lacustrine and Riverine Nonpersistent Emergents |
| | | L | 2 | EM | 2 None | E, F, G, H, K None or U | |
| | | R | 2, 3 | EM | 2 None | E, F, G, H, K None or U | |
| 6 | Tidal Fresh Marsh | R | 1 | EM | 2, None | Fresh Tidal N, T | Riverine and Palustrine Freshwater Tidal Emergents |
| | | P | NA | EM | All, None | Fresh Tidal S, R, T | |
| 7 | Transitional Marsh / Scrub Shrub | E | 2 | SS, FO | 1, 2, 4 to 7,None | Tidal M, N, P None or U | Estuarine Intertidal, Scrub-shrub and Forested (ALL except 3 subclass) |
| 8 | Regularly Flooded Marsh (Saltmarsh) | E | 2 | EM | 1 None | Tidal N None or U | Only regularly flooded tidal marsh No intermittently flooded "P" water Regime |
| 9 | Mangrove **Tropical settings only, otherwise 7** | E | 2 | FO, SS | 3 | Tidal M, N, P None or U | Estuarine Intertidal Forested and Scrub-shrub, Broad-leaved Evergreen |
| 10 | Estuarine Beach old code BB and FL = US | E | 2 | US | 1,2 Important codes | Tidal N, P | Estuarine Intertidal Unconsolidated Shores |
| | | **E** | **2** | **US** | **None** | **Tidal N, P** | **Only when shores (need images or base map)** |
| 11 | Tidal Flat old code BB and FL =US | E | 2 | US | 3,4 None | Tidal M, N None or U | Estuarine Intertidal Unconsolidated Shore (mud or organic) and Aquatic Bed; Marine Intertidal Aquatic Bed |
| | | E | 2 | AB | All Except 1 | Tidal M, N None or U | |
| | | **E** | **2** | **AB** | **1** | **P** | **Specifically, for wind driven tides on the south coast of TX** |
| | | M | 2 | AB | 1, 3 None | Tidal M, N None or U | |
| 12 | Ocean Beach old code BB and FL = US | M | 2 | US | 1,2 Important | Tidal N, P | Marine Intertidal Unconsolidated Shore, cobble-gravel, sand |
| | | M | 2 | US | None | Tidal P | |
| 13 | Ocean Flat old code BB and FL = US | M | 2 | US | 3,4 None | Tidal M, N None or U | Marine Intertidal Unconsolidated Shore, mud or organic, (low energy coastline) |

Source, Bill Wilen, National Wetlands Inventory.

Table 4 (cont.): NWI Classes to SLAMM 6 Categories

| SLAMM Code | Name | System | Subsystem | Class | Subclass | Water Regime | Notes |
|---|---|---|---|---|---|---|---|
| | | NWI code characters | | | | | |
| 14 | Rocky Intertidal | M | 2 | RS | All<br>None | Tidal M, N, P<br>None or U | Marine and Estuarine Intertidal Rocky Shore and Reef |
| | | E | 2 | RS | All<br>None | Tidal M ,N, P<br>None or U | |
| | | E | 2 | RF | 2, 3<br>None | Tidal M, N, P<br>None or U | |
| | | E | 2 | AB | 1 | Tidal M, N<br>None or U | |
| 15 | Inland Open Water<br><br>old code OW = UB | R | 2 | UB, AB | All, None | All, None | Riverine, Lacustrine, and Palustrine Unconsolidated Bottom, and Aquatic Beds |
| | | R | 3 | UB, AB, RB | All, None | All, None | |
| | | L | 1, 2 | UB, AB, RB | All, None | All, None | |
| | | P | NA | UB, AB, RB | All, None | All, None | |
| | | R | 5 | UB | All | Only U | |
| 16 | Riverine Tidal Open Water<br>old code OW = UB | R | 1 | All<br><br>**Except EM** | All<br>None<br>**Except 2** | Fresh Tidal S, R, T, V | Riverine Tidal Open water<br><br>**R1EM2 falls under SLAMM Category 6** |
| 17 | Estuarine Open Water (no h* for diked / impounded)<br>old code OW=UB | E | 1 | All | All<br>None | Tidal L, M, N, P | Estuarine subtidal |
| 18 | Tidal Creek | E | 2 | SB | All,<br>None | Tidal M, N, P<br>Fresh Tidal R, S | Estuarine Intertidal Streambed |
| 19 | Open Ocean<br>old code OW = UB | M | 1 | All | All | Tidal L, M, N, P | Marine Subtidal and Marine Intertidal Aquatic Bed and Reef |
| | | M | 2 | RF | 1,3,<br>None | Tidal M, N, P<br>None or U | |
| 20 | Irregularly Flooded Marsh | E | 2 | EM | 1, 5<br>None | P | Irregularly Flooded Estuarine Intertidal Emergent marsh |
| | | **E** | **2** | **US** | **2, 3, 4<br>None** | **P** | **Only when these salt pans are associated with E2EMN or P** |
| 21 | Not Used | | | | | | |
| 22 | Inland Shore<br>old code BB and FL = US | L | 2 | US, RS | All | All Nontidal | Shoreline not pre-processed using Tidal Range Elevations |
| | | P | NA | US | All, None | All Nontidal<br>None or U | |
| | | R | 2, 3 | US, RS | All, None | All Nontidal<br>None or U | |
| | | R | 4 | SB | All, None | All Nontidal<br>None or U | |
| 23 | Tidal Swamp | P | NA | SS, FO | All, None | Fresh Tidal R, S, T | Tidally influenced swamp |

* **h=Diked/Impounded** - When it is desirable to model the protective effects of dikes, an additional raster layer must be specified.

** Farmed wetlands are coded Pf

**All:** valid components

**None:** no Subclass or Water regime listed

**U:** Unknown water regime

**NA:** Not applicable

**DATE 1/14/12010**

| Water Regimes | |
|---|---|
| Nontidal | A, B, C, E, F,G, J, K |
| Saltwater Tidal | L, M, N, P |
| Fresh Tidal | R, S,T, V |

Note: Illegal codes must be categorize by intent.
Old codes BB, FL = US
Old Code OW = UB

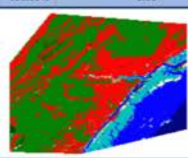
Source, Bill Wilen, National Wetlands Inventory

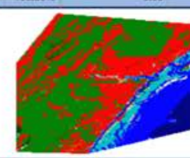
# Appendix G

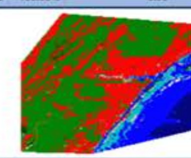
SLAMM 3.0 Output:

| 0.4m Sea Level Rise | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coverage Class | Base | | 2025 | | | | 2050 | | | | 2075 | | | | 2100 | | | | | |
| | Total Acres | % Coverage | Total Acres | % Coverage | Change from Base Acres | % Change from Base | Total Acres | % Coverage | Change from Base Acres | % Change from Base | Total Acres | % Coverage | Change from Base Acres | % Change from Base | Total Acres | % Coverage | Change from Base Acres | % Change from Base | | |
| [1] Developed Dry Land | 129.88 | 0.30% | 129.88 | 0.30% | 0.00 | 0.00% | 129.88 | 0.30% | 0.00 | 0.00% | 129.88 | 0.30% | 0.00 | 0.00% | 129.88 | 0.30% | 0.00 | 0.00% | | |
| [2] Undeveloped Dry Land | 14645.74 | 34.25% | 12933.73 | 30.25% | -1712.01 | -11.69% | 12863.27 | 30.08% | -1782.47 | -12.17% | 12847.14 | 30.04% | -1798.60 | -12.28% | 12779.99 | 29.89% | -1865.75 | -12.74% | | |
| [3] Swamp | 16876.64 | 39.47% | 18588.04 | 43.47% | 1711.40 | 10.14% | 18658.50 | 43.63% | 1781.86 | 10.56% | 18674.53 | 43.67% | 1797.89 | 10.65% | 18576.59 | 43.44% | 1699.95 | 10.07% | | |
| [5] Inland Fresh Marsh | 110.75 | 0.26% | 110.75 | 0.26% | 0.00 | 0.00% | 110.75 | 0.26% | 0.00 | 0.00% | 110.75 | 0.26% | 0.00 | 0.00% | 110.75 | 0.26% | 0.00 | 0.00% | | |
| [6] Tidal Fresh Marsh | 127.03 | 0.30% | 127.64 | 0.30% | 0.61 | 0.48% | 127.64 | 0.30% | 0.61 | 0.48% | 127.75 | 0.30% | 0.71 | 0.56% | 127.95 | 0.30% | 0.92 | 0.72% | | |
| [7] Transitional Salt Marsh | 41.65 | 0.10% | 41.65 | 0.10% | 0.00 | 0.00% | 41.34 | 0.10% | -0.31 | -0.73% | 35.43 | 0.08% | -6.21 | -14.91% | 161.32 | 0.38% | 119.67 | 287.35% | | |
| [8] Regularly Flooded Marsh | 3283.05 | 7.68% | 3080.45 | 7.20% | -202.59 | -6.17% | 2718.52 | 6.36% | -564.53 | -17.20% | 2233.44 | 5.22% | -1049.61 | -31.97% | 1741.14 | 4.07% | -1541.91 | -46.97% | | |
| [10] Estuarine Beach | 423.19 | 0.99% | 395.78 | 0.93% | -27.40 | -6.48% | 345.00 | 0.81% | -78.18 | -18.48% | 280.78 | 0.66% | -142.41 | -33.65% | 258.31 | 0.60% | -164.88 | -38.96% | | |
| [11] Tidal Flat | 92.34 | 0.22% | 75.43 | 0.18% | -16.91 | -18.31% | 46.86 | 0.11% | -45.48 | -49.26% | 127.17 | 0.30% | 34.83 | 37.72% | 163.42 | 0.38% | 71.09 | 76.99% | | |
| [12] Ocean Beach | 1.12 | 0.00% | 0.92 | 0.00% | -0.20 | -18.18% | 0.71 | 0.00% | -0.41 | -36.36% | 0.56 | 0.00% | -0.56 | -50.00% | 0.56 | 0.00% | -0.56 | -50.00% | | |
| [15] Open Water | 67.19 | 0.16% | 67.19 | 0.16% | 0.00 | 0.00% | 67.19 | 0.16% | 0.00 | 0.00% | 67.19 | 0.16% | 0.00 | 0.00% | 67.19 | 0.16% | 0.00 | 0.00% | | |
| [16] Riverine Tidal Open Water | 5549.74 | 12.98% | 5478.52 | 12.81% | -71.22 | -1.28% | 5578.26 | 13.05% | 28.52 | 0.51% | 5647.53 | 13.21% | 97.79 | 1.76% | 5755.67 | 13.46% | 205.93 | 3.71% | | |
| [19] Open Ocean | 724.71 | 1.69% | 1047.68 | 2.45% | 322.96 | 44.56% | 1390.86 | 3.25% | 666.15 | 91.92% | 1811.00 | 4.24% | 1086.28 | 149.89% | 2234.12 | 5.22% | 1509.41 | 208.28% | | |
| [20] Irregularly Flooded Marsh | 214.06 | 0.50% | 209.42 | 0.49% | -4.63 | -2.16% | 208.30 | 0.49% | -5.75 | -2.69% | 193.94 | 0.45% | -20.11 | -9.40% | 180.19 | 0.42% | -33.86 | -15.82% | | |
| [23] Tidal Swamp | 454.40 | 1.06% | 454.40 | 1.06% | 0.00 | 0.00% | 454.40 | 1.06% | 0.00 | 0.00% | 454.40 | 1.06% | 0.00 | 0.00% | 454.40 | 1.06% | 0.00 | 0.00% | | |
| [25] Inland Shore | 19.15 | 0.04% | 19.15 | 0.04% | 0.00 | 0.00% | 19.15 | 0.04% | 0.00 | 0.00% | 19.15 | 0.04% | 0.00 | 0.00% | 19.15 | 0.04% | 0.00 | 0.00% | | |
| Totals: | 42760.63 | 100.00% | 42760.63 | 100.00% | 0.00 | N/A | 42760.63 | 100.00% | 0.00 | N/A | 42760.63 | 100.00% | 0.00 | N/A | 42760.63 | 100.00% | 0.00 | N/A | | |

10 km







## Appendix H

<u>SLR 0.4 Meter Rise Scenario</u>

| Percent Change for SLAMM Values | Initial Value | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| **SLR (eustatic)** | 0.00 | 0.0337 | 0.1236 | 0.2392 | 0.36 |
| **Swamp** | 132155.83 | -0.01% | -0.02% | -0.02% | -0.02% |
| **Cypress Swamp** | 21940.94 | 0.00% | 0.00% | 0.00% | 0.00% |
| **Inland-Fresh Marsh** | 1511.10 | -0.03% | -0.04% | -0.10% | -0.28% |
| **Tidal-Fresh Marsh** | 191.17 | 0.00% | 0.00% | 0.00% | 0.00% |
| **Trans. Salt Marsh** | 32.53 | 27.88% | -13.24% | -4.66% | -7.72% |
| **Regularly-Flooded Marsh** | 3331.19 | -24.41% | -25.53% | -28.36% | 0.00% |
| **Mangrove** | 186.70 | -27.39% | -28.14% | -28.26% | -28.57% |
| **Estuarine Beach** | 160.29 | -27.78% | -28.15% | -28.45% | -28.62% |
| **Tidal Flat** | 41.43 | 41.95% | 76.65% | 150.61% | 204.13% |
| **Inland Open Water** | 196.82 | -1.09% | -1.40% | -2.19% | -2.53% |
| **Riverine Tidal** | 49.11 | 0.00% | 0.00% | 0.00% | 0.00% |
| **Estuarine Open Water** | 809.09 | 17.21% | 119.67% | 129.00% | 142.01% |
| **Irreg.-Flooded Marsh** | 4.37 | 4.44% | 8.88% | -54.22% | -47.99% |
| **Tidal Swamp** | 224.66 | -7.91% | -10.03% | -10.91% | -11.93% |
| **Freshwater Non-Tidal** | 155607.87 | -0.01% | -0.01% | -0.02% | -0.02% |
| **Open Water** | 1055.02 | 12.99% | 91.52% | 98.52% | 108.44% |
| **Low Tidal** | 201.72 | -9.02% | -6.63% | 8.33% | 19.19% |
| **Saltmarsh** | 3331.19 | -24.41% | -25.53% | -28.36% | -31.85% |
| **Transitional** | 223.60 | -12.82% | -25.25% | -25.34% | -25.92% |
| **Freshwater Tidal** | 415.83 | -4.27% | -5.42% | -5.90% | -6.44% |

## Appendix I

SLR A1B Scenario

| Percent Change for SLAMM Values (A1B Scenario ~0.6 Meter Rise) | Initial Value | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| SLR (eustatic) | 0.00 | 0.0337 | 0.1236 | 0.2392 | 0.36 |
| Swamp | 132155.83 | -0.01% | -0.02% | -0.02% | -0.05% |
| Cypress Swamp | 21940.94 | 0.00% | 0.00% | 0.00% | 0.00% |
| Inland-Fresh Marsh | 1511.10 | -0.03% | -0.06% | -0.29% | -1.24% |
| Tidal-Fresh Marsh | 191.17 | 0.00% | 0.00% | 0.00% | 0.00% |
| Trans. Salt Marsh | 32.53 | 42.45% | -5.63% | 6.09% | 58.53% |
| Regularly-Flooded Marsh | 3331.19 | -25.07% | -26.20% | -31.96% | -71.34% |
| Mangrove | 186.70 | -27.72% | -28.23% | -28.58% | -28.60% |
| Estuarine Beach | 160.29 | -27.86% | -28.28% | -28.65% | -47.44% |
| Tidal Flat | 41.43 | 51.45% | 102.89% | 151.17% | 199.45% |
| Inland Open Water | 196.82 | -1.11% | -1.83% | -2.45% | -2.65% |
| Riverine Tidal | 49.11 | 0.00% | 0.00% | 0.00% | 0.00% |
| Estuarine Open Water | 809.09 | 12.19% | 121.52% | 132.22% | 161.19% |
| Irreg.-Flooded Marsh | 4.37 | 4.44% | -32.78% | -32.78% | -33.53% |
| Tidal Swamp | 224.66 | -8.55% | -10.59% | -11.95% | -27.10% |
| Freshwater Non-Tidal | 155607.87 | -0.01% | -0.02% | -0.02% | -0.05% |
| Open Water | 1055.02 | 9.14% | 92.85% | 100.94% | 123.12% |
| Low Tidal | 201.72 | -0.67% | -1.34% | 57.75% | 195.00% |
| Saltmarsh | 3331.19 | -25.07% | -26.20% | -31.96% | -71.34% |
| Transitional | 223.60 | -8.38% | -24.30% | -23.56% | -2.10% |
| Freshwater Tidal | 415.83 | -4.62% | -5.72% | -6.46% | -14.64% |